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Issued August 26, 1907.

U. S. DEPARTMENT OF AGRICULTURE,
FOREST SERVICE—Circular 108.
GIFFORD PINCHOT, Forester

The Strength of Wood as Influenced by Moisture.

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GOVERNMENT PRINTING OFFICE : WASHINGTON : 1907

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THE STRENGTH OF WOOD AS INFLUENCED BY MOISTURE.

GENERAL PRINCIPLES.

The strength and stiffness of wood depend largely upon the degree to which it is seasoned. Roughly speaking, strength is the capacity of wood to sustain a load without breaking, stiffness the degree to which wood under a load resists distortion of form. As seasoning progresses the strength increases, so that by simply drying a piece of green spruce it is possible to multiply its strength four times. Stiffness is similarly increased by drying, though less markedly.

It is obvious, therefore, that strength values obtained in timber tests hold only for the given degree of moisture at which the tests were made. Since a weak wood, such as pine, in a state of absolute dryness, may be much stronger than a strong one, such as oak or hickory, in its green state, tables giving the mechanical properties of wood as derived from timber tests are of little value unless the moisture content of the different specimens is known.

In the ordinary process of seasoning, however, certain factors are introduced which greatly modify the effect of lessened moisture. Checking, for instance, always occurs to some extent. In large timbers this may counterbalance, partially or even entirely, the gain in strength due to the drying.

Since wood is very hygroscopic and readily absorbs moisture from the air, an increase to 400 per cent of the green strength (as in the case cited above) would not occur in practice. When exposed after drying, even when protected from the weather, wood will absorb moisture according to the humidity of the air, amounting in this climate to from 8 to 16 per cent of the dry weight. Assuming a condition of about 12 per cent, the strength would be thus again reduced to about 240 per cent of the green value.

With large timbers in commercial use it is not safe to count upon any greater strength, even after seasoning, than that of the green condition. Years of air seasoning are required before such timbers part with enough moisture to reach the fiber-saturation point, which, as will presently be explained, is the point in drying at which the strength of wood first begins to increase. With small, perfect stock, however, such as is used in the manufacture of implements and carriages, in

sizes up to about 4 by 4 inches in cross section, ordinary air drying may be counted upon to increase the strength between 50 and 150 per cent.

The stiffness follows a law similar to that of the strength, as may be seen in the tables of the modulus of elasticity, but the changes are of a less degree. This law is also well indicated by the relative steepness of the stress diagrams in figure 4 (page 14), which are arranged in order of dryness.

It is clearly important that the physical effects of moisture upon wood should be known, and that reliable means should be found for reducing all test values to a standard degree of moisture for engineering tables, as well as for adapting these standard strength values to wood in other conditions of moisture. To secure the needed data, an investigation has been carried on at the Yale Forest School laboratory, New Haven, Conn., during the past three years, involving several thousand mechanical tests on specially prepared material. A brief statement of the results obtained is given in the following pages and tables.[a]

METHODS OF TESTING.

Since the methods of conducting the tests are fully described in Bulletin 70[b] and Circular 38[c] of the Forest Service, only essential points need be discussed here.

In testing wood to determine the effect of a given factor upon the strength, a few well chosen and properly treated specimens serve better than a number of heterogeneous samples. The selection of the test specimens and their proper treatment to secure the desired conditions constituted the chief part of the problem, and required much more time and attention than the tests themselves.

The specimens were carefully cut and placed in series, so that each series consisted of a number of specimens, cut either from the same strip of wood or from adjacent strips in the log or plank, having practically the same straight grain, and free from defects. Each specimen in a series was brought to a different moisture degree in such a manner that the moisture was uniformly distributed. From 7

[a] For former investigations of the effect of moisture upon strength, reference is made to the following:

Mittheilungen aus dem Technischen Laboratorium der K. Tech. Hochschule in München. Bauschinger, Heft IX (Mitt. X), 1883. Untersuchungen über die Bautechnische Qualität des Fichtenholzes, Janka, in Baumaterialienkunde, Heft 17, No. 17, p. 262, Sept., 1904, Stuttgart.

Materials of Construction, Johnson, pp. 668, 669.

Bulletin 8, Forest Service, p. 23.

Bulletin 13, Forest Service, p. 19.

[b] The Effect of Moisture upon the Strength and Stiffness of Wood, by Tiemann.

[c] Instructions to Engineers of Timber Tests, by W. Kendrick Hatt.

to 16 of such series of specimens were made for each species of wood and each kind of test.

Tests were made in bending, compression parallel to grain, shearing parallel to grain, and compression at right angles to grain. The sizes of the specimens used were 2 by 2 by 40 inches for bending, with a span of 36 inches; 2 by 2 by $5\frac{3}{4}$ and 2 by 2 by 12 inches for compression parallel to grain and at right angles to grain, respectively; and 2 by 2 by 3 inches for shearing tests in the case of longleaf pine, red spruce, and chestnut. Smaller sizes were used for the subsequent tests upon loblolly pine, red gum, Douglas fir, Norway pine, and tamarack.

The results of the tests were plotted on cross-section paper, and graphically averaged by drawing a separate curve for each series. These series curves were then averaged for the average curve of the species.

The compression tests parallel to grain gave the most uniform and reliable results, and therefore formed the chief subject of the study. Bending tests were made upon the first three species, and also enough upon the next three to establish the fact that the law derived from compression tests applies also to beams. While shearing tests tend to show that shearing strength is increased in drying, they are too erratic to be reliable, probably because of minute checks caused by strains. It is accordingly unsafe to count upon any increase in the shearing strength of wood beyond that of the green condition. For this reason shearing tests were not made upon all of the woods tested.

The moisture was determined by cutting a cross-sectional disk at the point of failure an inch or less in thickness and drying this to constant weight at the boiling point of water. The weight of moisture lost in drying is expressed as a per cent of this dry weight and represents the "moisture per cent" at which the test was made. Other disks were also taken to determine the distribution of moisture. Experiments were made to determine the amount of moisture still remaining in the disk after drying in the manner just described by further drying in vacuum, the average result of which showed that about 0.7 per cent of moisture remained when the disks were dried by the ordinary method. The amount of volatile oils and other matter which escaped in drying the disks was found to be negligible.[a]

THE FIBER-SATURATION POINT.

Moisture exists in green wood in two conditions—that which is in the substance of the cell walls and that which fills the pores or the lumina of the cells, like honey in a comb. The latter, which may be

[a] For other references to moisture determinations see Forest Service Bulletin 6, p. 47; Bulletin 13, p. 19; or Circular 12, p. 7, of quarto edition or p. 11 of octavo edition. For a study of volatile oil and turpentine distribution see Bulletin 8, p. 34.

spoken of as "free" water, has no direct influence upon the strength. Under given conditions the cell walls become saturated with a definite amount of water and will absorb no more, although the wood may continue to absorb free water. The degree of moisture at which

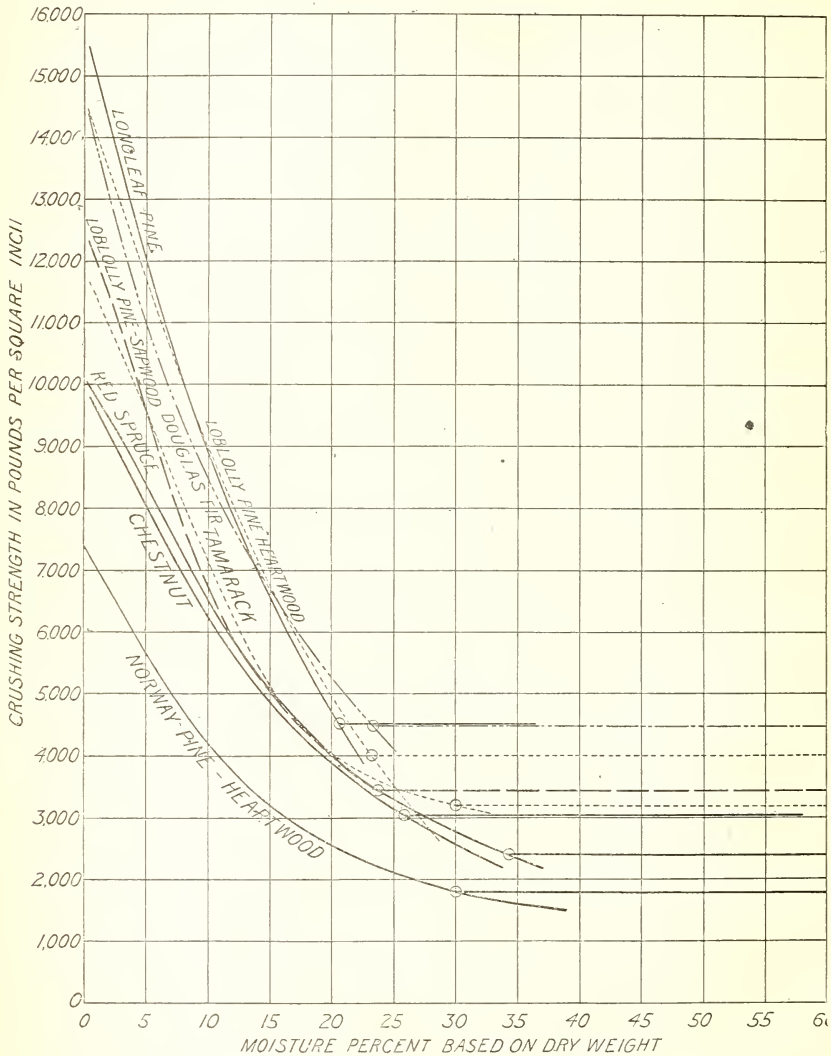

FIG. 1.—Relation between the crushing strength in compression parallel to grain, and the moisture content for several woods.

maximum absorption by the cell walls is reached is called the fiber-saturation point of the wood. After this point is reached added moisture does not lessen the strength of wood. At this point, also, wood ceases to swell.[a]

[a] See Forest Service Bulletin 13, p. 20, and Circular 12, p. 7.

Beginning with the dry condition, it will be seen from figures 1 and 2 that with increase of moisture the strength at first falls off very rapidly, then more slowly until the fiber-saturation point is reached,

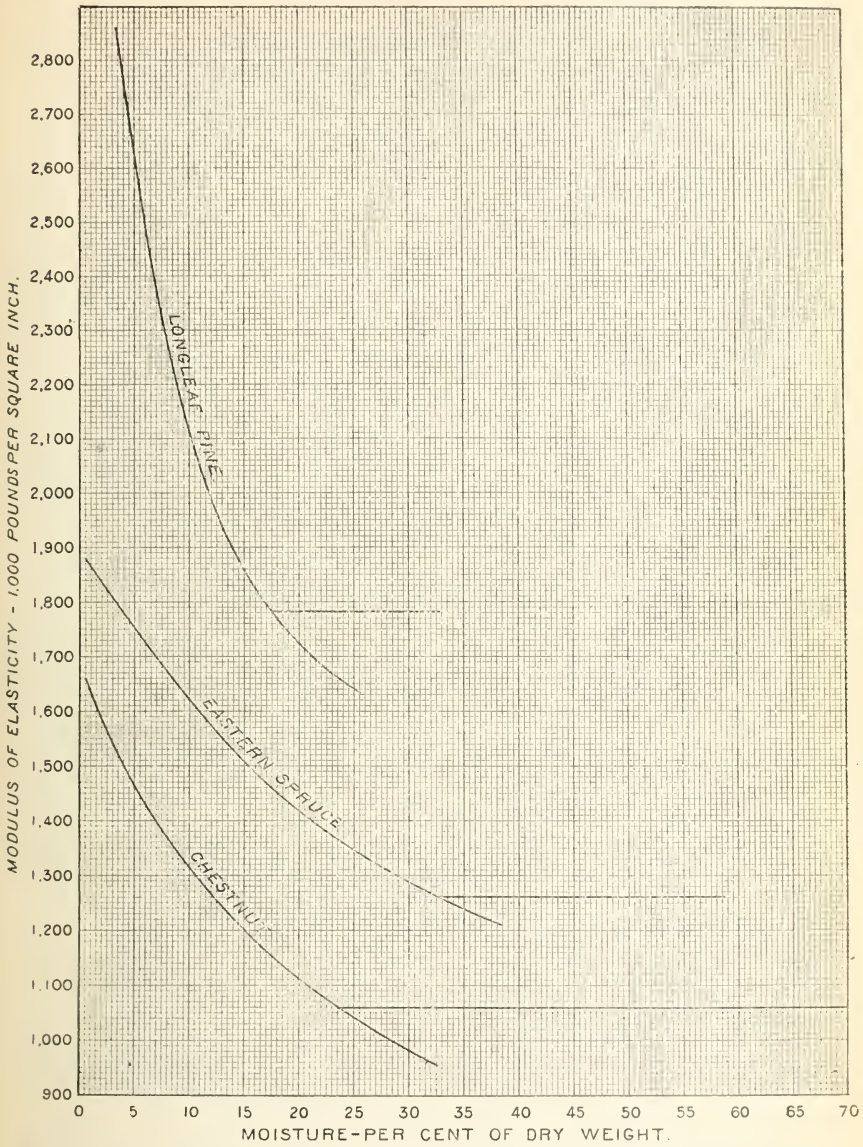

FIG. 2.—Relation between the stiffness (modulus of elasticity) in bending and moisture content, for three species.

where it abruptly ceases to decrease; so that the diagram for the greater moisture per cents becomes a horizontal line. The excess of moisture per cent after the fiber-saturation point is passed is there-

fore the amount of free water. There is no way of distinguishing the amount of free water present by the moisture determination alone.

The best way to determine the fiber-saturation point is by actual tests of the strength of very small specimens. Compression tests

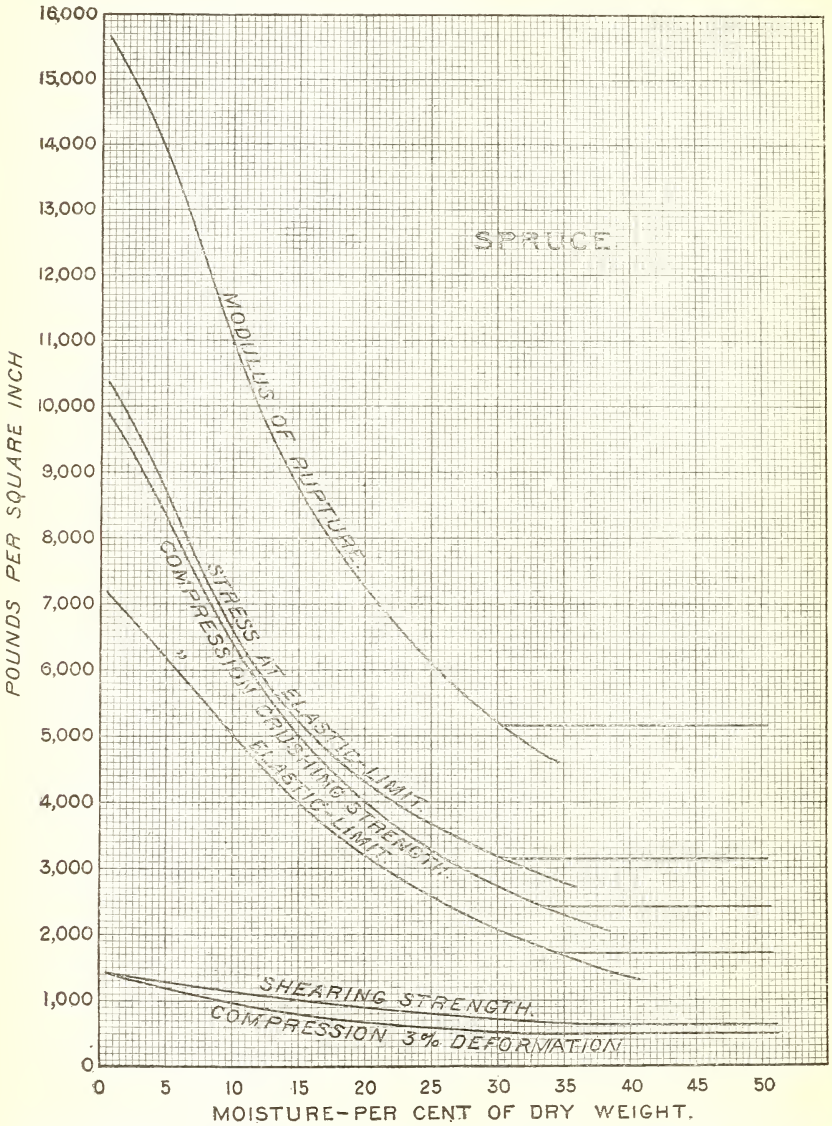

FIG. 3.—Comparison of the relations between strength and moisture content for red spruce in various kinds of tests. (The lowest curve is for compression at right angles to grain.)

similar to the moisture-strength tests were made for this purpose upon series of very small specimens—from one to one and a half inches long and from half an inch to one square inch in cross section. It is better

to use such small pieces for these tests, because they may be brought more accurately to the desired moisture condition, and with more uniform distribution of moisture, and also because greater uniformity may thus be obtained in the structure of the specimens of each series.

Table 1 gives the results of these determinations upon several kinds of wood. This critical moisture condition is found to change with different treatments and under different conditions. The moisture degree of the saturation point is higher for wood previously dried, and especially for wood which has been subjected to high temperatures, than it is for green wood. In some cases it also differs for heartwood and sapwood.

TABLE 1.—*The fiber-saturation point for several woods as determined by compression tests on small specimens.*

Kind of wood.	Nominal size.	Number of series used.	Number of tests.	Kiln-dry specific gravity.			Moisture per cent at fiber-saturation point.		
				Av.	Max.	Min.	Av.	Max.	Min.
Longleaf pine	¾ by ¾ by 1½	5	40	0.62	0.67	0.58	25	26	24
Red spruce	¾ by ¾ by 1½	5	40	.38	.42	.37	31	35	29
Chestnut	¾ by ¾ by 1½	5	40	.48	.54	.42	25	28	24
Loblolly pine heartwood	¾ by ¾ by 1¼								
Green		3	24	.59	.62	.57	23	.....	.....
Air-dry		10	80	.67	.72	.63	24	.....	.....
Loblolly pine sapwood	¾ by ¾ by 1¼								
Green		8	72	.47	.51	.45	24	.....	.....
Air-dry		10	80	.55	.61	.50	26	.....	.....
White ash	0.71 by 0.71 by 1.5.	7	49	.79	.85	.68	20	23	19
Red gum, air-dry	⅞ by ⅞ by 1½	5	45	.52	.55	.49	25	.....	.....
Douglas fir	1 by 1 by 1½	7	49	[b].58	.....	.....	23	.....	.....
		4	[a]16						
Norway pine	0.71 by 0.71 by 1½.								
Heartwood		11	121	.42	.50	.38	30	34	27
Sapwood		8	88	.44	.49	.41	28	30	26
Tamarack	0.71 by 0.71 by 1½.	11	121	.54	.68	.56	30	33	27

Unless otherwise stated determinations were made upon green wood.

[a] Two separate determinations.
[b] Value taken from other specimens cut from the same planks.

SUMMARY OF MOISTURE-STRENGTH RELATIONS.

In Table 2 is given for the seven species tested a condensed statement of the average strength values derived from curves, at three moisture conditions—green or wet, air-dry, and kiln-dry. The ratio of increase in strength above that of the green condition is given just below each strength value. The number of tests used, the average specific gravity, and the average number of rings per inch are also given in the table.

TABLE 2.—*Summary of moisture-strength tests. Average strength values at important moisture conditions.*

[The ratios of increase in strength over the green condition are given below each strength value.]

Moisture condition.	Moisture.	Compression parallel to grain. Crushing strength (pounds per square inch). Longleaf pine.	Red spruce	Loblolly pine. Heartwood.	Loblolly pine. Sapwood.	Norway pine.	Tamarack.	Chestnut.	Douglas fir.	Red gum,[a] half heart and half sap.
	Per cent.									
Green or soaked cold while green.	Over 30.	4,500	2,400	4,000	3,450	1,800	3,200	3,030	4,500	(b)
		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Normal air dry	12.	7,750	5,800	8,000	5,900	3,680	6,230	5,550	7,640	6,300
		1.70	2.40	2.00	1.70	2.00	1.90	1.80	1.70	
Kiln dry, at 130° to 145° F.	3.5.	13,000	8,900	12,450	10,500	6,140	10,180	8,500	11,900	9,400
		2.90	3.70	3.10	3.00	3.40	3.20	2.80	2.60	
Resoaked after drying.	Over 30.	4,040	2,190	.....	[c]3,090	1,600	2,940	2,500	.....	2,500
		.90	.91		.896	.89	.92	.82		
Number of tests used	.....	49	128	70	70	108	99	58	60	40
Specific gravity, kiln-dry wood.	.....	.63	.41	.65	.53	.40	.57	.46	.58	Sap .55 / Heart .50
Number rings per inch.	.....	26	17.5	7.5	6.3	7.1	14	5.9	6.2	.....

Moisture condition.	Moisture.	Compression parallel to grain. Stress at elastic limit (pounds per square inch). Longleaf pine.	Red spruce	Loblolly pine. Heartwood.	Loblolly pine. Sapwood.	Norway pine.	Tamarack.	Chestnut.	Douglas fir.	Red gum,[a] half heart and half sap.
	Per cent.									
Green or soaked cold while green.	Over 30.	3,450	1,700	3,100	2,580	940	2,140	2,470	3,500	(b)
		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Normal air dry	12.	5,800	4,550	5,700	3,840	2,050	3,830	3,800	5,450	4,070
		1.70	2.70	1.80	1.50	2.20	1.80	1.50	1.60	
Kiln dry, at 130° to 145° F.	3.5.	9,150	6,450	8,800	6,800	3,630	6,900	5,950	7,920	6,400
		2.70	3.80	2.80	2.60	3.90	3.20	2.40	2.30	
Resoaked after drying.	Over 30.	3,320	1,260	.....	[c]2,470	1,080	2,240	1,980	.....	1,800
		.96	.74		.956	1.15	1.05	.80		
Number of tests used	.....	49	128	70	70	108	99	58	60	40
Specific gravity, kiln-dry wood.	.....	.63	.41	.65	.53	.40	.57	.46	.58	Sap .55 / Heart .50
Number rings per inch.	.....	26	17.5	7.5	6.3	7.1	14	5.9	6.2	.....

Moisture condition.	Moisture.	Bending. Modulus of rupture (pounds per square inch). Longleaf pine.	Red spruce.	Douglas fir.	Chestnut.	Stress at elastic limit (pounds per square inch). Longleaf pine.	Red spruce.	Douglas fir.	Chestnut.	Modulus of elasticity (thousand pounds per square inch). Longleaf pine.	Red spruce.	Douglas fir.	Chestnut.
	Per cent.												
Green or soaked cold while green.	Over 30	8,900	5,170	9,230	6,040	4,920	3,170	5,650	3,580	1,780	1,260	1,630	1,060
		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Normal air dry	12	13,300	10,000	13,550	9,500	7,750	5,900	9,250	5,800	1,990	1,575	1,980	1,260
		1.50	1.90	1.50	1.60	1.60	1.90	1.60	1.60	1.10	1.25	1.20	1.20
Kiln dry, at 130° to 145° F.	3.5	22,000	14,500	14,800	12,600	14,100	9,300	11,670	8,200	2,830	1,795	2,130	1,520
		2.50	2.80	1.60	2.10	2.90	2.90	2.10	2.30	1.60	1.40	1.30	1.40
Resoaked after drying.	Over 30	[e]9,040	[d]4,460	.....	[e]5,260	[e]4,650	[d]2,860	.....	3,420	[e]1,635	[d]1,150	.....	[e]1,040
		1.02	.86		.87	.95	.90		.96	.92	.91		.98
Number of tests used	.....	30	67	36	45	29	65	36	51	30	65	36	52
Specific gravity kiln-dry wood	.....	.66	.42	.57	.47	.66	.42	.57	.47	.66	.42	.57	.47
Number rings per inch.	.....	16	17.5	9.1	6.7	16	17.5	9.1	6.7	16	17.5	9.1	6.7

[a] Proportionate result from other tests on green wood and air-dried wood resoaked forty-nine days. [b] From air-dry material. All other species except the red gum were treated from green wood which had never dried. [c] Average of four tests instead of five, corrected to correspond with the values in the table. [e] Average of four tests instead of ten, corrected to correspond with the values in the table. [d] Average of ten tests instead of twelve.

Figure 1 shows three general groups of moisture-strength curves, as follows: (1) Longleaf pine, loblolly pine heartwood, Douglas fir; (2) tamarack, loblolly pine sapwood; (3) red spruce, chestnut. Norway pine heartwood is similar to the tamarack, but falls far below it. It will be noted that there is a marked difference between the several species in the abruptness with which the strength begins to increase at the fiber-saturation points.

Examining the ratios of the increase in strength over that of the green condition, it is seen that the ratios for spruce are greater than those for longleaf pine. This, however, does not indicate that the rate of increase is greater, for the reason, as will be seen from the curves, that the moisture degree of the fiber saturation of spruce is greater than that of pine, so that the green condition is brought farther down the curve. In point of fact the rate of increase is greatest in longleaf pine, as is shown by the steepness of the curve. It seems reasonable to suppose that the resin in longleaf pine prevents the cell walls from absorbing as much water as does spruce, and consequently renders the strength of the wood greater under the same atmospheric conditions. It appears, moreover, to stiffen the cell walls at the same moisture degree, and so add to the strength of the wood, particularly in the dry condition, thus rendering the moisture-strength curve steeper. Comparing spruce and chestnut, it will be seen that, while chestnut is stronger than spruce in the green condition, spruce is the stronger when dry, in spite of the fact that chestnut has the greater specific gravity. Weight for weight in the dry state, however, red spruce is the strongest and longleaf pine the weakest of these three woods. In the green condition the reverse is the case.

Weight for weight, kiln-dry spruce is actually as strong and stiff in compression and bending as fairly good steel, and considerably stronger than cast iron.

SHRINKAGE.

When a piece of green or wet wood is dried no change in dimensions takes place until the fiber-saturation point is reached. The wood then begins to shrink in cross-sectional area until no further moisture can be extracted from the cell walls. It also shrinks longitudinally, but in most species the amount of this shrinkage is so small as to be negligible. The shrinkage in area in drying, from the green to the oven-dried condition, varies with different woods, ranging from as much as 20 per cent with hickory to as little as 7 per cent with red cedar. Since the shrinkage along the grain is negligible, the change in area represents also the change in volume.

The results of measurements taken upon the regular moisture-strength test pieces of longleaf pine, spruce, and chestnut show that the swelling increases with the per cent of moisture. Thus, starting with wood in the oven-dry condition and figuring the swelling in per

cent of the dry volume (the moisture being figured in per cent of the dry weight), the per cent of swelling increases with the moisture per cent (forming a straight line in the diagram), but at a less rapid ratio, until the fiber-saturation point is reached, where it abruptly ceases. In figure 4 the average results of these measurements are given as percentages of swelling based on the dry volumes.

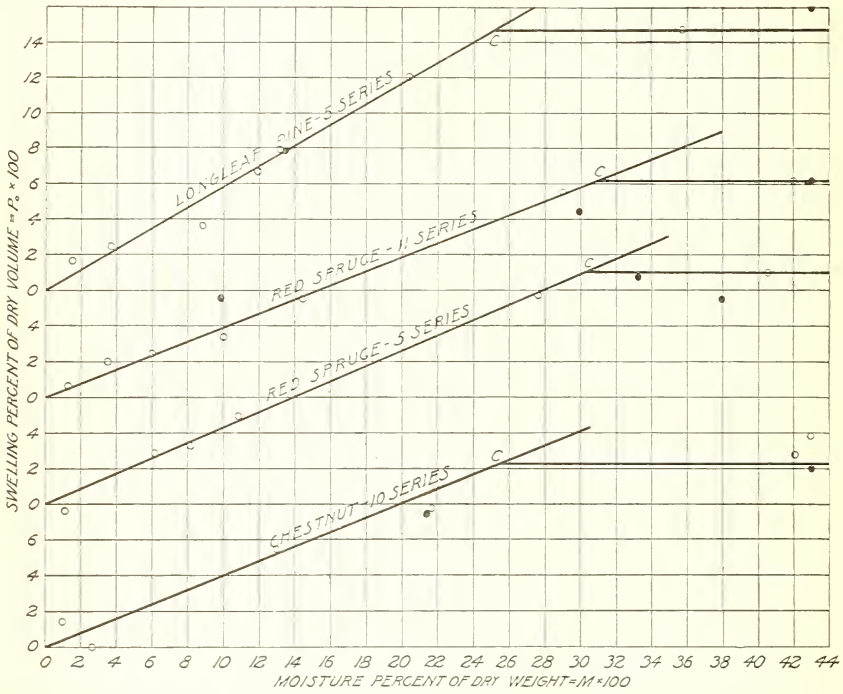
LONGLEAF PINE-5 SERIES
RED SPRUCE-11 SERIES
RED SPRUCE-5 SERIES
CHESTNUT-10 SERIES
C
SWELLING PERCENT OF DRY VOLUME = P_s × 100
MOISTURE PERCENT OF DRY WEIGHT = M × 100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44

FIG. 4.—Relation between swelling and moisture. Each point is the average of from five to eleven specimens. Black dots indicate specimens that were kiln-dried and then allowed to reabsorb moisture. The fiber-saturation point is at *c*.

The specific gravity of wood is least in its perfectly dry condition, and if no swelling took place it would increase in the selfsame piece of wood directly with the amount of moisture absorbed. This is in fact the case after the fiber-saturation point has been passed, when the swelling ceases. But below this point, the wood continues to swell with increased absorption of moisture. Consequently the specific gravity ("conditional" specific gravity, as this is termed to distinguish it from the inherent specific gravity, which depends upon the density of the wood substance) increases in a less rapid ratio than the moisture.[a]

The fact that a piece of wood grows smaller as it dries modifies to some extent the figures given in the tables for the increase in strength when these are applied to the same stick. The figures as given are

[a] See also Janka: Baumaterialienkunde, Heft 17, p. 264, Sept., 1904, in which the variation of conditional specific gravity with moisture is given in a series of curves for spruce of various densities.

reckoned in terms of pounds per square inch of actual area, and would not apply directly for the selfsame block of wood; for if the area of the end of the block is 1 square inch when green, this area will be less than a square inch when the block is dry. The ratios of increase in strength given in the tables must therefore be multiplied by a shrinkage factor if applied to the selfsame stick of wood. The shrinkage factor for compression strength is simply the ratio of the area of the dry block to its original area when green.

With beams the change in the resisting moments produced by the change in dimensions must also be taken into consideration. The shrinkage factors, so far as determined, are given in Table 3.

TABLE 3.—*Shrinkage factors from green to kiln-dry (3½ per cent moisture) state.*

	Longleaf pine.	Red spruce.	Chestnut.	Loblolly pine.
Compression parallel to grain; crushing strength, elastic limit, and modulus of elasticity	0.90	0.92	0.90	0.92
Bending; modulus of rupture, and strength at elastic limit	.88	.89	.87	.89
Bending; modulus of elasticity	.85	.86	.84	.86

Since the swelling increases directly with the moisture, as seen from figure 4, intermediate strength values may readily be calculated from the figures given in this table.[a]

EFFECT OF CASEHARDENING.

If the moisture be unequally distributed in the specimen, as in the case of large timbers rapidly dried, or in "casehardened" pieces, the

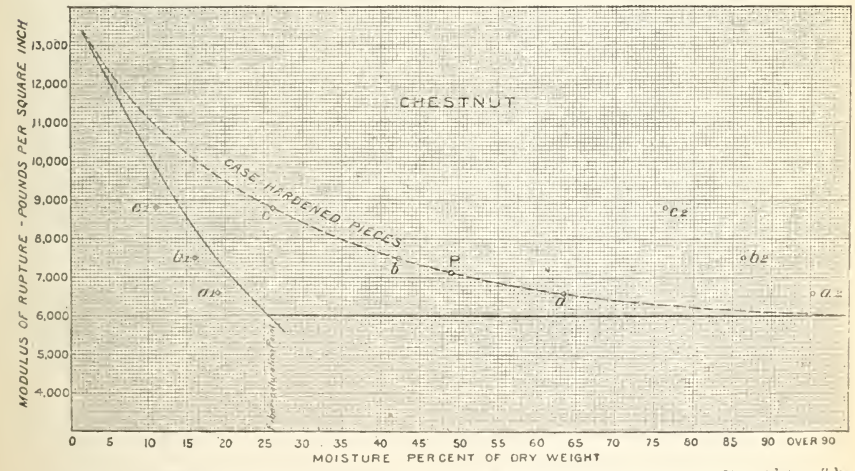

FIG. 5.—Effect of casehardening upon the form of the moisture-strength curve in bending tests. The upper curve is from casehardened specimens, the lower curve from uniformly dried specimens.

outer shell may be drier than the fiber-saturation point, while the inside still contains free water. The resulting moisture-strength curve will

[a] For other figures on shrinkage the reader is referred to Circular 12, p. 8, and Circular 19 of the Division of Forestry, and also to Bulletin 8, p. 30.

be higher than the correct curve and be so rounded off from the driest to the wettest condition as entirely to obscure the fiber-saturation point. Former investigators have erroneously taken this abnormal curve as the true moisture-strength curve. While Professor Johnson recognized what is here designated the fiber-saturation point, he disregarded it in his curves.

A number of tests were made, in compression parallel to grain and in bending, upon 2 by 2 inch specimens of chestnut, purposely case-

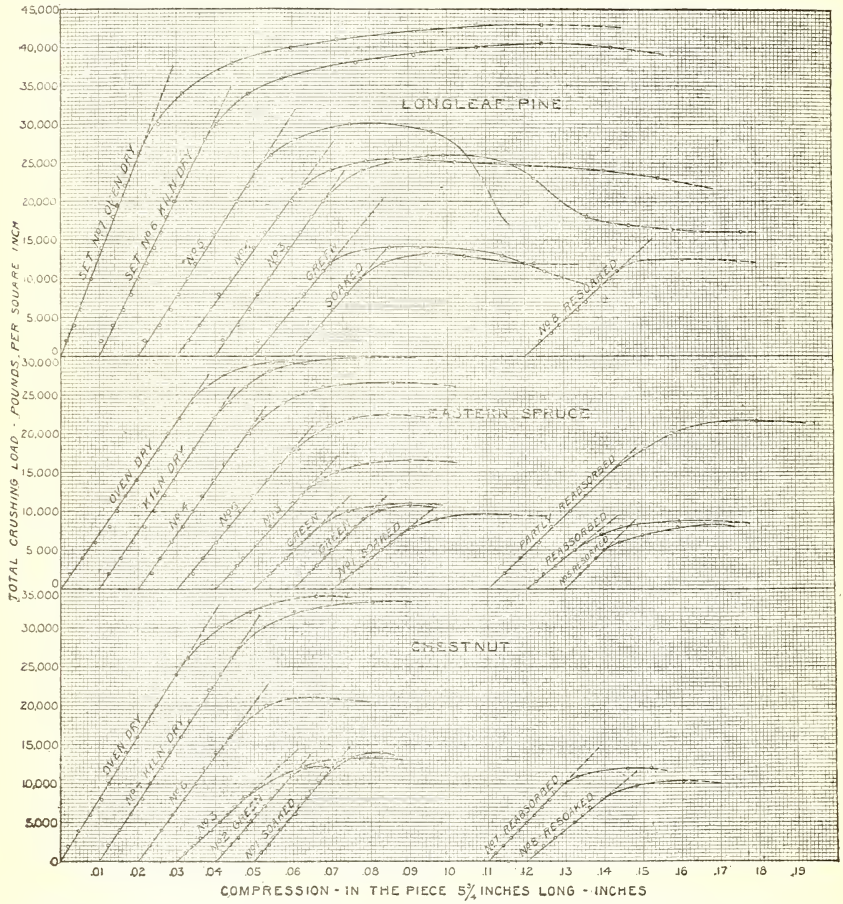

FIG. 6.—Stress diagrams of tests in compression parallel to grain for a single series of each of three species, showing the effect of different degrees of moisture from the wet to the oven-dry conditions.

hardened to three different depths. These were compared with the regular tests on specimens with evenly distributed moisture, and the results drawn in curves. Figure 5 gives one of the diagrams for bending tests. The upper curve represents the results of case-hardened tests and the lower that of regular tests. The contrast is very striking.

It follows, then, that tests for standard values should be made only upon specimens in which the moisture is uniformly distributed.

EFFECT OF THE PROCESS OF DRYING UPON WOOD.

Although dry wood is much stronger than wet wood, when it is brought back to the wet condition it is weaker than it was in its original green state. Certain methods of drying in particular may greatly and permanently injure its inherent strength. This result of drying is distinct from mechanical injuries, such as checks and the loosening of knots, which would be additional causes of weakening, and is due to changes produced in the physical condition of the wood.

Preliminary and correlated experiments along this line may be summarized as follows:

(1) No matter how dried, wood is found upon resoaking to be weaker than it was originally. The specimens which were treated in the moisture-strength study mentioned on page 11 show, with very few exceptions, a decided reduction in strength when resoaked after having been kiln-dried with moist heat up to about 130° F. The average loss is from 15 to 18 per cent of the original strength.

(2) The loss in strength upon resoaking or wetting is very great when wood has been dried by steaming under pressure. Experiments made upon loblolly pine railroad ties at St. Louis, described in circular 39 of the Forest Service,[a] show that steaming for four hours at 20 pounds pressure reduces the strength fully 15 per cent, and that the loss increases directly with the pressure and the length of time steamed, the loss ranging from 40 to 60 per cent after steaming at 100 pounds for four hours and exceeding 30 per cent after steaming at 20 pounds for twenty hours.

(3) Special tests, 147 in all, were made upon small specimens of green longleaf pine, spruce, and chestnut to determine directly the effect of steaming and dry air. For compression the test pieces were seven-eighths inch square and 1½ inches long, and for bending 14 inches long, with 12 inches span. Four sets were tested—(*a*) in the green condition; (*b*) steamed at 208° F. in exhaust steam (open to air) for several days, then resoaked; (*c*) dried in dry air at the same temperature, then resoaked; (*d*) steamed, as in *b*, and tested directly. The ratios of strength and moisture per cents are given in Table 4, where each figure gives, as a rule, the average of five tests.

[a] Experiments on the Strength of Treated Timber, by W. Kendrick Hatt.

TABLE 4.—*Loss of inherent strength when subsequently resoaked due to drying with exhaust steam and dry air.*

Species.	Set.	Treatment.	Compression parallel to grain.		Bending.	
			Strength. (a)	Moisture.	Modulus of rupture. a	Moisture.
				Per cent.		*Per cent.*
Longleaf pine	*a*	Tested green	100	26	100	28
	b	Steamed and resoaked	82	34	113	28
	c	Dry heat and resoaked	85	38	94	35
	d	Steamed	219	3.9	208	4.9
Red spruce	*a*	Tested green	100	39	100	44
	b	Steamed and resoaked	79	55	90	42
	c	Dry heat and resoaked	86	61	77	46
	d	Steamed	258	6.9	216	5.4
Chestnut	*a*	Tested green	100	100	100	110
	b	Steamed and resoaked	80	74	82	55
	c	Dry heat and resoaked	82	94	84	75
	d	Steamed	252	3.5	78	35

a Expressed in per cent of values for green wood.

In general, it may be concluded from these tests that drying in exhaust steam mixed with air reduces the strength of resoaked wood about 20 per cent, and drying in dry air at the same temperature reduces it slightly less. Other tests show that this loss is not due to the soaking process. When subsequently dried, the effect is entirely different, as will be seen further on. It seems probable, also, that the resoaked wood gradually recovers its strength if left in the water a long time without decay. Whether it would finally regain its original green strength or not is still a mooted question.

(4) Table 5 summarizes the effects of various methods of steaming, drying, and soaking upon the strength of wood as shown in the results of some preliminary tests. These tests were made upon small blocks three-fourths inch square and 1½ inches long, for ultimate crushing strength parallel to grain only. The blocks were cut from seven strips; each series of tests, 1 to 14, from the same strip, and the correspondingly numbered blocks were treated alike and the results averaged. Thus each figure in the table is the average of seven tests. Thoroughly green wood was used to start with. The steaming was done at atmospheric pressure with exhaust steam, the kiln-drying at about 120° to 130° F., the oven-drying at 208° F., and the soaking in a glass jar in which the water was changed several times. There was no sign of fungous growth. All three species were soaked in the same jar.

TABLE 5.—*The effect of various processes of drying, steaming, and soaking upon the strength of wood. Preliminary tests on small specimens.*

Consecutive number of sets in the strips.	Compression parallel to grain.						Condition.
	Longleaf pine.		Red spruce.		Chestnut.		
	Average total load.	Average moisture.	Average total load.	Average moisture.	Average total load.	Average moisture.	
	Pounds.	*Per cent.*	*Pounds.*	*Per cent.*	*Pounds.*	*Per cent.*	
1	2,902	25.5	2,211	29.1	2,075	98.6	Green.
12	2,946	26.1	2,219	29.6	2,221	98	Do.
6	3,031	27.5	2,294	30.5	2,194	98	Do.
2	2,213	57.9	1,553	72.6	1,482	125	Air-dried 98 days, resoaked 47 days, indoors.
3	2,268	67.6	1,606	91.9	1,573	131	Kiln-dried 35 days, resoaked 63 days, indoors.
4	2,251	70.1	1,606	97.5	1,566	127	Air-dried 33 days, oven 2 days at 208° F., resoaked 68 days.
5	2,355	70.3	1,650	104.0	1,511	133	Kiln-dried 35 days, soaked 68 days; kiln-dried 56 days, soaked 36 days; kiln-dried 41 days, soaked 43 days.
7	2,224	61.8	1,569	87.1	1,573	120	Air-dried 33 days, oven over 8 days, resoaked 53 days.
8	2,291	34.8	1,815	29.6	1,486	59.5	Steamed 4 hours and tested when cool.
9	2,041	68.3	1,426	94.4	1,271	134	Steamed 4 hours, air-dried 63 days, resoaked 47 days.
10	2,409	22.4	1,518	59.2	1,257	40	Steamed 21 hours during 4 days and tested when cool.
11	1,967	95.4	1,321	117.0	917	154	Steamed 21 hours during 4 days, air-dried 57 days, resoaked 47 days.
13	6,988	1.16	6,626	1.0	5,103	0.86	Steamed 7 hours, then oven-dried 5 days.
14	6,890	1.53	6,519	0.7	5,057	0.76	Air-dried 31 days, oven-dried 3 days.

The results shown in Table 5 lead to the following conclusions:

(*a*) *Comparing Nos. 13 and 14.*—Steaming at atmospheric pressure does not appear to impair the strength of wood when the wood is subsequently brought to the dry condition.

(*b*) *Comparing Nos. 2, 9, and 11.*—Steaming permanently reduces the strength in the wet condition; that is, it permanently raises the moisture degree of the fiber-saturation point, even if the wood is thoroughly dried after the steaming, and steaming for twenty-one hours is more detrimental in this respect than for a shorter time.

(*c*) *Comparing Nos. 2, 3, 4, and 7.*—Drying in dry air at the boiling point of water (gradually raising the temperature) is little or no more harmful than drying at a low temperature of about 130° F., even if prolonged for eight days. Possibly with pine and spruce a lower temperature, and a shorter time at the higher temperature, are slightly more advantageous.

It would appear from No. 2 that even air-drying at ordinary temperature results in a weakening when the wood is brought back to the wet condition. This inference must not be made too hastily, however, for it is possible that some of this difference may be accounted for by difference of temperature at time of test. Set No. 1 was tested in February at about 55° F., while No. 2 was tested in July, on a very hot day, probably at about 80° F. Until more exact knowledge has

been obtained as to the effect of temperature upon the strength of wet wood no definite conclusion as to the cause of this difference can be made.

(*d*) Repeated alternate kiln-drying and resoaking (No. 5) apparently causes no greater loss in strength than kiln-drying and soaking only once, except in the case of chestnut.

These deductions must be considered as provisional, pending further experiments now in progress. They agree, however, with the results previously mentioned, in so far as the cases are parallel. Experiments thus far made establish beyond question the extreme mutability of the strength values of wood as affected by extrinsic conditions, and consequently the absolute necessity of a knowledge of all the conditions before comparing the values obtained from tests made upon different specimens, or compiling a standard table of the strength values for small sizes of different woods.

Briefly, then, in addition to the inherent qualities of the specimens under consideration, account must be taken of previous treatment, present moisture condition, temperature, and speed and method of testing.

EFFECT OF SUPERHEATING.

Experiments now in progress indicate that drying wood at high temperatures, either in steam or in dry air, produces the following results: (1) It permanently reduces its moisture content below that of ordinary air-dried wood when again exposed to the air, at the same time rendering it less hygroscopic, so that it is less susceptible to changes in the humidity of the air; (2) the moisture condition of the fiber-saturation point is changed, being reduced by high temperatures with dry air or superheated steam; (3) the strength of the wood is increased, except in the resoaked condition.

These effects differ in degree according to the method of drying and the temperature sustained.

To what extent the brittleness of wood is affected by drying under these conditions is not yet determined, but comparisons of the stress diagrams and failures of white ash beams seem to indicate little or no change in this respect. Whether the increase in strength is due to the reduction in hygroscopicity or to physical changes is of secondary importance, since in either case the strength of the wood under like atmospheric conditions is increased.

It is possible that after long exposure this difference in hygroscopicity might disappear. However, some of the specimens upon which this conclusion is based were exposed to the open air for more than eight months, and were much wetter when placed on the rack to air dry after treatment than were the air-dried pieces with which they were compared.

EQUATION FOR THE MOISTURE-DENSITY-STRENGTH RELATION FOR LONGLEAF PINE.

An equation derived from the curves of the longleaf pine compression tests, giving the variation of crushing strength both with specific gravity and with moisture per cent, is:

$$C=G\,(22.1p^2-1335p+25610).$$

Where C=crushing strength in pounds per square inch.
G=specific gravity of dry wood.
p=per cent of moisture, based on disk method.

Thus, for example, what is the crushing strength of a piece of longleaf pine at 10 per cent of moisture, its dry specific gravity being 0.62?

$$C=0.62\,(2210-13350+25610)=8{,}971.4 \text{ pounds per square inch.}$$

The maximum variation from this equation of a single test was 17 per cent above and 22 per cent below; of a single series, 9 per cent above and 22 per cent below. (For any value beyond the saturation point, p should be taken as 24.)

In closing, it may well be remarked that the effect of water in softening organic tissue, as in wetting a piece of paper or a sponge, is a very familiar fact; so, also, the stiffening effect of drying, especially at high temperatures. The ultimate cause of the result is purely hypothetical, but that the same law which applies to other organic substances should, with proper modifications, hold good in relation to the strength of wood seems highly reasonable. Since wood is a very complex structure, composed of many substances, concerning the exact chemical and physical nature of which very little is known, it is impossible to theorize with any degree of certainty as to the influence of moisture, heat, and other extrinsic factors. The laws are extremely subtle, and can only be determined empirically from large numbers of actual tests.

Approved:
JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *June 8, 1907.*

[Cir. 108.]

APPENDIX.

MOISTURE-STRENGTH REDUCTION TABLES.

Tables 6 to 24 have been compiled from the average moisture-strength curves of the various woods. They present, in a form convenient for general use, the factors or coefficients by which the strength value at any given moisture degree should be multiplied in order to find the equivalent value at the standard or any other desired moisture degree. For example: A number of compression tests upon air-dry longleaf pine gave an average compression strength of 7,860 pounds per square inch. The moisture per cent was found to be 12. What is the corresponding strength of the green wood? In Table 6 (p. 24) look under the column headed 12 per cent for the factor which is on the line headed "green" (or 20.3 per cent) and find the number 0.581. Then 7,860 times 0.581=4,567 pounds per square inch, which is the value sought.

It should be noted that these reduction tables can be used with certainty only for the adjustment of groups of data, and not for any single datum.

TABLE 6.—*Reduction factors for longleaf pine.*

[Compression parallel to grain—maximum crushing strength.]

TO— Moisture per cent.	FROM— Moisture per cent.											
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	20.3.[a]	22.
2	1	1.120	1.265	1.425	1.605	1.81	2.05	2.32	2.65	3.05	3.12	3.60
4	.894	1	1.13	1.275	1.435	1.62	1.83	2.07	2.37	2.73	2.79	3.22
6	.790	.885	1	1.125	1.27	1.43	1.62	1.835	2.09	2.45	2.47	2.84
8	.702	.785	.888	1	1.125	1.27	1.44	1.63	1.86	2.14	2.19	2.53
10	.623	.698	.788	.887	1	1.13	1.28	1.445	1.65	1.90	1.945	2.24
12	.552	.618	.699	.786	.885	1	1.13	1.28	1.46	1.685	1.725	1.99
14	.488	.546	.617	.695	.783	.884	1	1.13	1.29	1.49	1.52	1.755
16	.431	.482	.545	.614	.691	.781	.884	1	1.14	1.315	1.345	1.55
18	.377	.422	.478	.538	.605	.684	.774	.876	1	1.15	1.18	1.36
20	.328	.367	.414	.467	.526	.593	.672	.760	.867	1	1.02	1.18
[a] 20.3	.320	.359	.406	.457	.514	.581	.657	.744	.849	.978	1	1.155
22	.278	.311	.351	.396	.445	.503	.569	.645	.735	.848	.866	1

[a] Green.

TABLE 7.—*Reduction factors for red spruce.*

[Compression parallel to grain—maximum crushing strength.]

TO—Moisture per cent.	FROM—Moisture per cent.																
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	32.	34.[a]
2	1	1.08	1.19	1.325	1.47	1.62	1.79	1.98	2.16	2.35	2.54	2.77	2.98	3.19	3.42	3.69	3.92
4	.926	1	1.10	1.225	1.36	1.50	1.66	1.83	2.00	2.18	2.35	2.56	2.76	2.95	3.17	3.41	3.63
6	.841	.908	1	1.11	1.235	1.36	1.505	1.665	1.82	1.98	2.14	2.33	2.51	2.68	2.88	3.10	3.29
8	.756	.816	.899	1	1.11	1.225	1.35	1.495	1.63	1.78	1.92	2.09	2.25	2.41	2.58	2.79	2.96
10	.681	.736	.810	.902	1	1.105	1.22	1.35	1.47	1.60	1.73	1.885	2.03	2.17	2.33	2.51	2.67
12	.617	.667	.734	.817	.907	1	1.105	1.22	1.335	1.45	1.57	1.705	1.84	1.97	2.11	2.37	2.42
14	.554	.598	.658	.732	.813	.896	1	1.105	1.21	1.315	1.42	1.545	1.665	1.78	1.91	2.06	2.19
16	.505	.546	.601	.669	.742	.820	.914	1	1.09	1.19	1.285	1.40	1.51	1.61	1.73	1.86	1.98
18	.463	.500	.550	.613	.680	.750	.836	.915	1	1.09	1.175	1.28	1.38	1.475	1.58	1.705	1.815
20	.426	.460	.506	.564	.625	.690	.769	.842	.920	1	1.08	1.18	1.27	1.355	1.455	1.57	1.67
22	.394	.425	.468	.521	.578	.638	.711	.778	.851	.925	1	1.09	1.175	1.255	1.345	1.45	1.54
24	.362	.391	.430	.479	.531	.586	.654	.715	.782	.850	.919	1	1.08	1.15	1.235	1.335	1.42
26	.335	.362	.399	.443	.492	.543	.606	.663	.724	.787	.851	.926	1	1.07	1.15	1.235	1.31
28	.314	.339	.373	.415	.461	.508	.567	.621	.678	.737	.797	.867	.936	1	1.07	1.155	1.23
30	.292	.316	.348	.387	.430	.474	.528	.579	.632	.690	.743	.808	.873	.932	1	1.08	1.145
32	.271	.293	.323	.359	.398	.440	.490	.536	.586	.637	.689	.750	.810	.865	.928	1	1.06
a 34	.255	.276	.304	.338	.375	.414	.461	.505	.551	.600	.649	.706	.762	.814	.874	.941	1

[a] Green.

TABLE 8.—*Reduction factors for chestnut.*

[Compression parallel to grain—maximum crushing strength.]

TO—Moisture per cent.	FROM—Moisture per cent.													
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	25.5.[a]	26.
2	1	1.09	1.205	1.34	1.49	1.64	1.82	1.98	2.17	2.36	2.60	2.82	3.00	3.05
4	.917	1	1.105	1.23	1.37	1.505	1.67	1.815	1.99	2.17	2.39	2.59	2.76	2.80
6	.830	.904	1	1.11	1.24	1.36	1.51	1.64	1.80	1.96	2.16	2.34	2.49	2.53
8	.747	.814	.901	1	1.115	1.225	1.36	1.48	1.62	1.765	1.945	2.11	2.25	2.28
10	.670	.730	.808	.896	1	1.10	1.22	1.325	1.45	1.585	1.74	1.89	2.01	2.05
12	.610	.664	.735	.816	.910	1	1.11	1.205	1.32	1.44	1.585	1.72	1.835	1.865
14	.549	.598	.662	.735	.820	.901	1	1.085	1.19	1.30	1.43	1.55	1.65	1.68
16	.505	.551	.609	.677	.754	.829	.920	1	1.09	1.195	1.315	1.425	1.52	1.545
18	.461	.503	.556	.617	.688	.757	.840	.914	1	1.09	1.20	1.30	1.385	1.41
20	.423	.461	.510	.566	.631	.694	.770	.837	.916	1	1.10	1.19	1.27	1.29
22	.384	.419	.464	.515	.574	.631	.700	.761	.834	.909	1	1.085	1.155	1.175
24	.355	.387	.428	.475	.530	.582	.646	.702	.770	.839	.923	1	1.065	1.085
[a] 25.5	.333	.363	.401	.446	.497	.546	.606	.659	.721	.786	.865	.938	1	1.015
26	.327	.356	.395	.438	.488	.537	.596	.648	.710	.775	.851	.921	.984	1

[a] Green.

TABLE 9.—*Reduction factors for longleaf pine.*

[Bending—modulus of rupture.]

TO— Moisture per cent.	FROM— Moisture per cent.												
	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	25.[a]	26.
4	1	1.14	1.30	1.45	1.60	1.73	1.87	1.99	2.11	2.22	2.33	2.39	2.45
6	.877	1	1.14	1.27	1.41	1.52	1.64	1.75	1.855	1.945	2.01	2.10	2.15
8	.770	.877	1	1.115	1.235	1.335	1.44	1.535	1.625	1.71	1.79	1.845	1.885
10	.690	.786	.896	1	1.105	1.195	1.29	1.375	1.455	1.53	1.605	1.65	1.69
12	.624	.711	.811	.904	1	1.08	1.165	1.24	1.32	1.385	1.455	1.495	1.53
14	.577	.658	.750	.836	.925	1	1.08	1.15	1.22	1.28	1.345	1.38	1.415
16	.535	.610	.695	.775	.857	.927	1	1.065	1.13	1.185	1.245	1.28	1.31
18	.502	.572	.653	.728	.804	.870	.938	1	1.06	1.115	1.17	1.20	1.23
20	.474	.540	.616	.687	.759	.821	.885	.935	1	1.05	1.105	1.135	1.16
22	.451	.514	.586	.654	.723	.781	.843	.898	.951	1	1.05	1.08	1.105
24	.429	.490	.558	.623	.689	.745	.804	.856	.906	.954	1	1.03	1.05
[a]25	.418	.476	.543	.606	.670	.725	.782	.832	.882	.927	.973	1	1.025
26	.408	.466	.531	.592	.655	.708	.761	.814	.862	.906	.95[illegible]	.978	1

[a]Green.

TABLE 10.—*Reduction factors for red spruce.*

[Bending—modulus of rupture.]

TO—Moisture per cent.	FROM—Moisture per cent.															
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	31.5.[a]
2	1	1.055	1.13	1.245	1.37	1.505	1.635	1.78	1.915	2.07	2.21	2.37	2.53	2.69	2.87	2.91
4	.950	1	1.075	1.18	1.30	1.43	1.555	1.69	1.82	1.97	2.10	2.25	2.40	2.55	2.72	2.76
6	.884	.930	1	1.10	1.21	1.33	1.445	1.57	1.695	1.835	1.955	2.09	2.25	2.37	2.53	2.57
8	.804	.846	.910	1	1.10	1.21	1.315	1.43	1.54	1.67	1.78	1.905	2.03	2.16	2.30	2.34
10	.731	.769	.826	.909	1	1.10	1.195	1.30	1.40	1.515	1.62	1.73	1.845	1.965	2.09	2.13
12	.665	.700	.753	.827	.910	1	1.085	1.185	1.275	1.38	1.47	1.575	1.68	1.785	1.905	1.935
14	.612	.644	.692	.761	.837	.920	1	1.09	1.17	1.27	1.355	1.45	1.545	1.645	1.755	1.78
16	.562	.591	.636	.699	.769	.845	.918	1	1.08	1.165	1.245	1.33	1.42	1.51	1.61	1.635
18	.522	.544	.591	.649	.714	.785	.853	.930	1	1.085	1.155	1.235	1.32	1.40	1.495	1.52
20	.482	.507	.545	.600	.659	.725	.788	.858	.924	1	1.065	1.14	1.22	1.295	1.38	1.40
22	.451	.476	.511	.562	.618	.680	.739	.805	.866	.938	1	1.07	1.14	1.215	1.295	1.315
24	.422	.444	.478	.525	.577	.635	.690	.752	.809	.876	.934	1	1.065	1.135	1.21	1.23
26	.396	.417	.448	.492	.541	.595	.647	.704	.757	.821	.875	.937	1	1.06	1.135	1.15
28	.372	.392	.421	.463	.509	.560	.608	.663	.713	.772	.824	.882	.941	1	1.065	1.085
30	.349	.367	.395	.434	.477	.525	.571	.621	.668	.725	.772	.826	.882	.938	1	1.015
a 31.5	.344	.362	.389	.427	.470	.517	.562	.611	.659	.714	.760	.814	.868	.923	.985	1

[a] Green.

TABLE 11.—*Reduction factors for chestnut.*

[Bending—modulus of rupture.]

TO—Moisture per cent.	FROM—Moisture per cent.													
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	25.2.[a]	26.
2	1	1.055	1.125	1.20	1.29	1.385	1.485	1.59	1.71	1.83	1.96	2.09	2.18	2.23
4	.916	1	1.065	1.135	1.22	1.31	1.405	1.51	1.62	1.73	1.86	1.975	2.06	2.11
6	.890	.940	1	1.07	1.145	1.23	1.32	1.42	1.52	1.625	1.745	1.855	1.94	1.98
8	.834	.880	.935	1	1.075	1.15	1.235	1.325	1.42	1.52	1.635	1.74	1.815	1.855
10	.775	.820	.872	.931	1	1.07	1.15	1.235	1.325	1.415	1.52	1.62	1.69	1.73
12	.723	.763	.813	.868	.933	1	1.075	1.15	1.235	1.32	1.42	1.51	1.575	1.61
14	.672	.711	.757	.809	.869	.931	1	1.075	1.15	1.23	1.32	1.405	1.465	1.50
16	.628	.663	.706	.754	.810	.868	.933	1	1.07	1.145	1.23	1.31	1.365	1.40
18	.586	.618	.659	.704	.755	.810	.871	.934	1	1.07	1.15	1.22	1.275	1.305
20	.548	.578	.616	.658	.706	.758	.814	.872	.935	1	1.07	1.145	1.19	1.22
22	.509	.538	.573	.612	.658	.705	.757	.811	.870	.931	1	1.065	1.11	1.135
24	.479	.506	.539	.575	.618	.663	.712	.764	.818	.875	.940	1	1.045	1.07
a25.2	.460	.485	.516	.551	.594	.646	.684	.732	.785	.840	.902	.957	1	1.02
26	.448	.474	.505	.534	.579	.620	.667	.715	.766	.820	.880	.936	.977	1

[a] Green.

TABLE 12.—*Reduction factors for longleaf pine.*

[Bending—modulus of elasticity.]

TO— Moisture per cent.	FROM— Moisture per cent.												
	2.	4.	6.	8.	10.	12.	14.	16.	17.5.[a]	18.	20.	22.	24.
2	1	1.09	1.20	1.31	1.42	1.51	1.59	1.65	1.69	1.70	1.75	1.78	1.82
4	.92	1	1.11	1.20	1.31	1.39	1.46	1.52	1.55	1.57	1.61	1.63	1.67
6	.831	.903	1	1.09	1.18	1.26	1.32	1.37	1.40	1.41	1.45	1.47	1.57
8	.765	.830	.92	1	1.08	1.16	1.21	1.26	1.29	1.30	1.33	1.36	1.39
10	.705	.766	.848	.922	1	1.06	1.12	1.16	1.19	1.20	1.23	1.25	1.28
12	.661	.720	.796	.865	.938	1	1.05	1.09	1.12	1.13	1.15	1.18	1.20
14	.630	.684	.753	.824	.894	.952	1	1.04	1.06	1.07	1.10	1.12	1.15
16	.607	.659	.730	.794	.860	.917	.964	1	1.02	1.03	1.06	1.08	1.10
a 17.5	.592	.645	.714	.776	.842	.897	.944	.977	1	1.01	1.03	1.05	1.08
18	.588	.640	.708	.770	.835	.889	.935	.970	.992	1	1.03	1.05	1.07
20	.573	.623	.690	.750	.813	.866	.910	.946	.966	.975	1	1.02	1.04
22	.564	.612	.678	.737	.799	.851	.895	.928	.950	.957	.983	1	1.02
24	.550	.598	.662	.720	.780	.832	.875	.908	.928	.935	.960	.977	1

[a] Green.

TABLE 13.—*Reduction factors for red spruce.*

[Bending—modulus of elasticity.]

TO—Moisture per cent.	FROM—Moisture per cent.																
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	32.	32.8.[a]
2	1	1.03	1.07	1.10	1.14	1.17	1.20	1.23	1.26	1.29	1.32	1.35	1.38	1.41	1.43	1.45	1.46
4	.968	1	1.03	1.07	1.10	1.13	1.16	1.20	1.22	1.25	1.28	1.31	1.33	1.36	1.38	1.40	1.41
6	.938	.969	1	1.05	1.07	1.10	1.13	1.16	1.19	1.21	1.24	1.27	1.29	1.32	1.34	1.36	1.37
8	.908	.938	.969	1	1.05	1.06	1.09	1.12	1.15	1.17	1.20	1.23	1.25	1.28	1.30	1.32	1.35
10	.881	.910	.939	.970	1	1.03	1.06	1.09	1.11	1.14	1.17	1.19	1.21	1.24	1.26	1.27	1.29
12	.856	.884	.913	.944	.972	1	1.05	1.06	1.08	1.11	1.13	1.16	1.18	1.20	1.22	1.24	1.25
14	.832	.859	.887	.916	.944	.971	1	1.03	1.05	1.07	1.10	1.13	1.15	1.17	1.19	1.20	1.22
16	.810	.832	.864	.892	.919	.946	.974	1	1.02	1.05	1.07	1.10	1.12	1.14	1.16	1.17	1.18
18	.791	.817	.843	.871	.898	.924	.951	.977	1	1.02	1.05	1.07	1.09	1.11	1.13	1.15	1.15
20	.774	.800	.826	.854	.879	.905	.931	.956	.980	1	1.02	1.05	1.07	1.09	1.11	1.12	1.13
22	.756	.781	.806	.833	.858	.882	.909	.934	.956	.975	1	1.02	1.04	1.06	1.08	1.10	1.10
24	.739	.764	.789	.814	.839	.864	.889	.914	.935	.955	.979	1	1.02	1.04	1.06	1.07	1.08
26	.725	.750	.774	.799	.823	.847	.872	.895	.918	.936	.960	.981	1	1.02	1.03	1.05	1.06
28	.712	.736	.759	.784	.808	.832	.856	.879	.901	.920	.942	.965	.981	1	1.02	1.03	1.04
30	.701	.725	.748	.772	.796	.819	.844	.865	.887	.905	.928	.949	.966	.985	1	1.02	1.02
32	.690	.714	.736	.760	.784	.806	.830	.853	.874	.891	.914	.934	.951	.970	.985	1	1.01
[a] 32.8	.685	.708	.730	.754	.778	.800	.824	.846	.864	.885	.906	.926	.943	.962	.977	.992	1

[a] Green.

TABLE 14.—*Reduction factors for chestnut.*

[Bending—modulus of elasticity.]

TO— Moisture per cent.	FROM— Moisture per cent.												
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.[a]	26.
2	1	1.06	1.11	1.16	1.21	1.26	1.30	1.34	1.38	1.43	1.47	1.50	1.54
4	.946	1	1.05	1.10	1.15	1.19	1.23	1.27	1.31	1.35	1.39	1.42	1.46
6	.902	.953	1	1.05	1.09	1.14	1.17	1.21	1.25	1.29	1.32	1.35	1.39
8	.861	.910	.955	1	1.04	1.08	1.12	1.16	1.19	1.23	1.26	1.29	1.33
10	.826	.873	.916	.960	1	1.04	1.07	1.11	1.14	1.18	1.21	1.24	1.27
12	.795	.840	.881	.923	.962	1	1.03	1.07	1.10	1.14	1.17	1.19	1.22
14	.770	.813	.853	.894	.931	.968	1	1.03	1.06	1.10	1.13	1.16	1.18
16	.744	.786	.825	.865	.901	.936	.968	1	1.03	1.06	1.09	1.12	1.15
18	.722	.764	.800	.839	.875	.908	.938	.970	1	1.03	1.06	1.09	1.11
20	.700	.740	.776	.814	.848	.881	.910	.940	.969	1	1.03	1.05	1.08
22	.681	.720	.755	.791	.825	.857	.885	.915	.942	.974	1	1.02	1.05
a 24	.665	.703	.737	.773	.806	.837	.865	.894	.920	.950	.976	1	1.02
26	.650	.687	.720	.755	.786	.818	.845	.873	.900	.928	.954	.977	1

[a] Green.

TABLE 15.—*Reduction factors for longleaf pine.*

[Bending—stress at elastic limit.]

TO—Moisture per cent.	FROM—Moisture per cent.												
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.[a]
2	1	1.13	1.31	1.53	1.75	1.99	2.20	2.39	2.54	2.70	2.85	2.99	3.14
4	.882	1	1.15	1.35	1.54	1.75	1.94	2.11	2.25	2.39	2.52	2.64	2.77
6	.767	.867	1	1.17	1.34	1.52	1.69	1.83	1.95	2.07	2.18	2.29	2.41
8	.656	.742	.856	1	1.15	1.30	1.44	1.57	1.67	1.77	1.87	1.96	2.06
10	.572	.648	.746	.882	1	1.13	1.26	1.37	1.45	1.54	1.63	1.71	1.80
12	.503	.570	.657	.768	.881	1	1.11	1.20	1.28	1.36	1.44	1.51	1.58
14	.455	.515	.594	.694	.795	.904	1	1.09	1.16	1.23	1.30	1.36	1.43
16	.419	.475	.547	.639	.733	.832	.921	1	1.07	1.13	1.19	1.25	1.32
18	.393	.445	.513	.600	.688	.781	.865	.938	1	1.06	1.12	1.17	1.24
20	.370	.420	.485	.565	.648	.735	.814	.884	.941	1	1.05	1.11	1.16
22	.351	.397	.458	.535	.614	.697	.771	.838	.893	.948	1	1.05	1.10
24	.335	.379	.437	.510	.585	.665	.735	.799	.851	.904	.954	1	1.05
[a]26	.318	.361	.415	.486	.556	.633	.700	.760	.810	.860	.908	.951	1

[a] Green.

TABLE 16.—*Reduction factors for red spruce.*

[Bending—stress at elastic limit.]

TO— Moisture per cent.	FROM— Moisture per cent.																
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	30.5.[a]	32.
2	1	1.08	1.20	1.35	1.50	1.67	1.83	1.97	2.14	2.29	2.47	2.59	2.75	2.92	3.08	3.11	3.16
4	.924	1	1.11	1.25	1.39	1.54	1.69	1.82	1.98	2.12	2.28	2.40	2.54	2.69	2.85	2.87	2.92
6	.833	.901	1	1.12	1.25	1.39	1.52	1.64	1.78	1.91	2.05	2.16	2.29	2.43	2.57	2.59	2.63
8	.741	.802	.890	1	1.21	1.24	1.35	1.46	1.59	1.70	1.83	1.92	2.04	2.16	2.28	2.30	2.34
10	.665	.720	.799	.897	1	1.11	1.20	1.31	1.42	1.52	1.64	1.73	1.83	1.94	2.05	2.07	2.10
12	.599	.649	.720	.808	.901	1	1.09	1.18	1.28	1.37	1.47	1.55	1.65	1.75	1.85	1.86	1.89
14	.548	.593	.659	.740	.825	.915	1	1.08	1.17	1.26	1.35	1.42	1.51	1.60	1.69	1.70	1.73
16	.508	.550	.610	.685	.764	.848	.925	1	1.09	1.16	1.25	1.32	1.40	1.48	1.56	1.58	1.60
18	.467	.505	.561	.630	.702	.780	.851	.920	1	1.07	1.15	1.21	1.28	1.36	1.44	1.45	1.41
20	.436	.472	.524	.589	.657	.728	.796	.860	.935	1	1.08	1.13	1.20	1.27	1.34	1.36	1.38
22	.406	.440	.487	.547	.610	.678	.740	.800	.870	.930	1	1.05	1.12	1.18	1.25	1.26	1.28
24	.386	.417	.463	.520	.580	.644	.703	.760	.826	.884	.950	1	1.06	1.12	1.19	1.20	1.22
26	.363	.393	.436	.490	.546	.607	.663	.715	.778	.832	.895	.942	1	1.06	1.12	1.13	1.15
28	.343	.371	.412	.463	.516	.572	.625	.676	.735	.786	.845	.889	.945	1	1.06	1.06	1.08
30	.325	.351	.390	.438	.488	.542	.592	.640	.695	.744	.800	.842	.894	.946	1	1.01	1.03
a30.5	.321	.348	.386	.434	.484	.537	.586	.631	.689	.737	.792	.834	.885	.937	.990	1	1.02
32	.317	.343	.380	.427	.476	.529	.577	.624	.678	.725	.780	.821	.811	.924	.975	.985	1

[a] Green.

TABLE 17.—*Reduction factors for chestnut.*

[Bending—stress at elastic limit.]

TO—Moisture per cent.	FROM—Moisture per cent.														
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	27.2.[a]	28.
2	1	1.11	1.22	1.33	1.44	1.53	1.65	1.76	1.90	2.00	2.12	2.25	2.41	2.49	2.54
4	.899	1	1.10	1.19	1.29	1.38	1.48	1.58	1.70	1.80	1.90	2.03	2.16	2.23	2.29
6	.820	.913	1	1.09	1.18	1.26	1.35	1.45	1.55	1.64	1.74	1.85	1.97	2.04	2.09
8	.753	.837	.918	1	1.08	1.16	1.24	1.33	1 43	1.51	1.59	1.70	1.81	1.87	1.92
10	.697	.775	.850	.926	1	1.07	1.15	1.23	1.32	1.39	1.48	1.57	1.68	1.73	1.77
12	.652	.725	.795	.866	.935	1	1.07	1.15	1.23	1.30	1.38	1.47	1.57	1.62	1.66
14	.607	.675	.740	.806	.871	.931	1	1.07	1.15	1.21	1.29	1.37	1.46	1.51	1.54
16	.568	.631	.692	.754	.814	.871	.935	1	1.07	1.13	1.20	1.28	1.37	1.41	1.44
18	.528	.588	.644	.701	.758	.810	.870	.931	1	1.06	1.12	1.19	1.27	1.31	1.34
20	.500	.556	.610	.665	.718	.767	.824	.881	.947	1	1.06	1.13	1.20	1.24	1.27
22	.472	.525	.575	.627	.677	.724	.778	.832	.894	.943	1	1.06	1.14	1.17	1.20
24	.444	.494	.541	.590	.637	.681	.731	.782	.840	.887	.940	1	1.07	1.10	1.13
26	.416	.462	.506	.552	.596	.638	.685	.747	.787	.831	.881	.936	1	1.03	1.06
[a] 27.2	.402	.448	.490	.534	.571	.617	.664	.708	.761	.804	.853	.906	.967	1	1.02
28	.393	.438	.479	.522	.564	.603	.648	.693	.745	.786	.833	.886	.946	.978	1

[a] Green.

TABLE 18.—*Reduction factors for loblolly pine sapwood.*

[Compression parallel to grain—maximum crushing strength.]

TO— Moisture per cent.	FROM— Moisture per cent.													
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.[a]	26.	28.
2	1	1.12	1.29	1.49	1.71	1.93	2.15	2.38	2.62	2.85	3.10	3.30	3.56	3.80
4	.895	1	1.15	1.33	1.53	1.73	1.92	2.12	2.34	2.55	2.77	2.96	3.18	3.40
6	.777	.869	1	1.16	1.33	1.50	1.67	1.84	2.04	2.21	2.41	2.57	2.77	2.95
8	.671	.750	.864	1	1.15	1.30	1.44	1.59	1.76	1.91	2.08	2.22	2.39	2.55
10	.584	.652	.751	.870	1	1.13	1.25	1.39	1.53	1.66	1.81	1.93	2.08	2.22
12	.518	.579	.666	.771	.888	1	1.11	1.23	1.36	1.47	1.60	1.71	1.84	1.97
14	.465	.520	.599	.693	.798	.899	1	1.10	1.22	1.33	1.44	1.54	1.66	1.77
16	.421	.471	.541	.627	.722	.814	.906	1	1.10	1.20	1.30	1.39	1.50	1.60
18	.382	.427	.491	.568	.654	.737	.820	.906	1	1.09	1.18	1.26	1.36	1.45
20	.351	.392	.452	.522	.601	.679	.755	.834	.920	1	1.09	1.16	1.25	1.33
22	.323	.361	.415	.481	.554	.624	.694	.766	.846	.920	1	1.07	1.15	1.23
[a]24	.303	.338	.390	.451	.519	.585	.650	.719	.793	.862	.937	1	1.08	1.15
26	.281	.314	.361	.418	.481	.542	.604	.666	.735	.800	.870	.927	1	1.07

[a] Green.

TABLE 19.—*Reduction factors for loblolly pine sapwood.*

[Compression parallel to grain—stress at elastic limit.]

TO—Moisture per cent.	FROM—Moisture per cent.													
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.[a]	26.	28.
2	1	1.15	1.35	1.57	1.78	1.96	2.16	2.32	2.52	2.65	2.80	2.96	3.15	3.29
4	.868	1	1.17	1.36	1.54	1.70	1.87	2.02	2.18	2.30	2.43	2.57	2.73	2.85
6	.741	.855	1	1.17	1.32	1.46	1.60	1.72	1.87	1.97	2.08	2.20	2.34	2.44
8	.636	.733	.857	1	1.13	1.25	1.37	1.48	1.60	1.69	1.78	1.88	2.00	2.09
10	.563	.649	.759	.885	1	1.10	1.21	1.31	1.42	1.49	1.57	1.67	1.77	1.85
12	.510	.588	.688	.802	.906	1	1.10	1.18	1.28	1.35	1.43	1.51	1.61	1.67
14	.464	.534	.625	.729	.824	.909	1	1.08	1.17	1.23	1.30	1.37	1.46	1.52
16	.430	.496	.580	.677	.765	.844	.928	1	1.08	1.14	1.20	1.27	1.35	1.41
18	.397	.458	.535	.625	.706	.779	.857	.923	1	1.05	1.11	1.18	1.25	1.30
20	.377	.435	.509	.593	.670	.740	.814	.876	.950	1	1.06	1.11	1.19	1.24
22	.358	.412	.482	.562	.635	.701	.771	.830	.900	.948	1	1.06	1.13	1.17
[a]24	.338	.389	.455	.531	.600	.662	.728	.784	.850	.895	.945	1	1.06	1.11
26	.318	.366	.428	.500	.565	.623	.685	.739	.800	.841	.889	.941	1	1.04

[a] Green.

TABLE 20.—*Reduction factors for Douglas fir.*

[Compression parallel to grain—maximum crushing strength.]

TO—Moisture per cent.	FROM—Moisture per cent.													
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	23.[a]	24.	26.
2	1	1.13	1.26	1.40	1.55	1.70	1.87	2.06	2.26	2.48	2.74	2.89	3.02	3.33
4	.885	1	1.12	1.24	1.37	1.50	1.65	1.82	2.00	2.19	2.42	2.56	2.67	2.94
6	.794	.896	1	1.11	1.22	1.35	1.48	1.63	1.79	1.96	2.16	2.29	2.39	2.64
8	.716	.809	.904	1	1.11	1.22	1.34	1.48	1.62	1.77	1.96	2.07	2.16	2.39
10	.647	.731	.816	.904	1	1.10	1.21	1.33	1.46	1.60	1.77	1.87	1.95	2.16
12	.589	.666	.744	.823	.911	1	1.10	1.22	1.33	1.46	1.61	1.70	1.78	1.96
14	.535	.605	.675	.747	.828	.909	1	1.10	1.21	1.32	1.46	1.55	1.62	1.78
16	.485	.548	.611	.677	.750	.824	.906	1	1.10	1.20	1.33	1.40	1.46	1.62
18	.443	.500	.559	.618	.685	.751	.828	.914	1	1.10	1.21	1.28	1.34	1.48
20	.404	.457	.510	.564	.625	.686	.755	.834	.914	1	1.10	1.17	1.22	1.35
22	.366	.413	.461	.510	.565	.621	.684	.754	.826	.905	1	1.06	1.10	1.22
a 23	.346	.392	.437	.484	.536	.588	.648	.715	.783	.856	.948	1	1.05	1.15
24	.331	.374	.418	.462	.511	.562	.619	.682	.748	.820	.905	.955	1	1.10

[a] Green.

TABLE 21.—*Reduction factors for Douglas fir.*

[Compression parallel to grain—stress at elastic limit.]

TO—Moisture per cent.	FROM—Moisture per cent.													
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	23.[a]	24.	26.
2	1	1.08	1.18	1.29	1.40	1.56	1.70	1.87	2.02	2.18	2.34	2.40	2.51	2.71
4	.929	1	1.09	1.20	1.30	1.45	1.58	1.73	1.88	2.03	2.17	2.23	2.33	2.52
6	.850	.916	1	1.10	1.19	1.32	1.45	1.59	1.72	1.86	1.99	2.04	2.14	2.31
8	.774	.834	.910	1	1.08	1.20	1.31	1.45	1.57	1.69	1.81	1.86	1.94	2.10
10	.714	.770	.839	.924	1	1.11	1.21	1.33	1.45	1.56	1.67	1.71	1.79	1.94
12	.643	.692	.755	.831	.900	1	1.09	1.20	1.30	1.40	1.50	1.54	1.61	1.74
14	.589	.635	.692	.761	.825	.916	1	1.10	1.19	1.29	1.38	1.41	1.48	1.60
16	.535	.577	.630	.692	.750	.834	.910	1	1.08	1.17	1.25	1.29	1.34	1.45
18	.494	.532	.580	.639	.691	.769	.839	.922	1	1.08	1.15	1.19	1.24	1.34
20	.458	.494	.538	.592	.642	.713	.778	.855	.928	1	1.07	1.10	1.15	1.24
22	.428	.461	.503	.554	.600	.666	.728	.800	.867	.935	1	1.03	1.07	1.16
a 23	.416	.449	.489	.538	.584	.648	.707	.778	.844	.909	.972	1	1.04	1.13
24	.398	.430	.468	.515	.558	.620	.677	.744	.807	.870	.930	.957	1	1.08

[a] Green.

TABLE 22.—*Reduction factors for Norway pine heartwood.*

[Compression parallel to grain—maximum crushing strength.]

TO—Moisture per cent.	FROM—Moisture per cent.															
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.[a]	32.
2	1	1.12	1.26	1.42	1.60	1.80	2.02	2.22	2.42	2.66	2.83	3.02	3.24	3.50	3.70	3.91
4	.895	1	1.12	1.27	1.43	1.61	1.80	1.98	2.16	2.38	2.53	2.71	2.90	3.14	3.31	3.50
6	.797	.891	1	1.13	1.28	1.43	1.61	1.77	1.93	2.12	2.26	2.41	2.59	2.79	2.95	3.12
8	.706	.790	.886	1	1.13	1.27	1.43	1.57	1.71	1.88	2.00	2.14	2.29	2.48	2.62	2.77
10	.624	.698	.783	.883	1	1.12	1.26	1.38	1.51	1.66	1.77	1.89	2.02	2.18	2.31	2.44
12	.556	.622	.698	.787	.891	1	1.12	1.23	1.35	1.48	1.57	1.68	1.81	1.95	2.06	2.18
14	.496	.554	.622	.701	.795	.891	1	1.10	1.20	1.32	1.40	1.50	1.61	1.74	1.83	1.94
16	.451	.504	.566	.638	.723	.811	.909	1	1.09	1.20	1.28	1.36	1.46	1.58	1.67	1.77
18	.413	.463	.518	.585	.662	.743	.834	.916	1	1.10	1.17	1.25	1.34	1.45	1.53	1.62
20	.376	.420	.471	.531	.602	.676	.758	.834	.909	1	1.06	1.14	1.22	1.32	1.39	1.47
22	.353	.395	.443	.500	.566	.635	.712	.783	.855	.940	1	1.07	1.15	1.24	1.31	1.38
24	.331	.370	.415	.468	.530	.594	.666	.734	.800	.880	.936	1	1.07	1.16	1.22	1.29
26	.308	.344	.386	.436	.494	.554	.621	.684	.745	.820	.872	.931	1	1.08	1.14	1.21
28	.286	.319	.358	.404	.457	.513	.576	.633	.691	.760	.809	.864	.927	1	1.06	1.12
[a]30	.271	.303	.340	.383	.433	.486	.545	.600	.655	.720	.766	.818	.878	.947	1	1.06
32	.256	.286	.320	.362	.409	.459	.515	.566	.618	.680	.724	.773	.830	.895	.944	1

[a] Green.

TABLE 23.—*Reduction factors for Norway pine heartwood.*

[Compression parallel to grain—stress at elastic limit.]

TO—Moisture per cent.	FROM—Moisture per cent.															
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.[a]	32.
2	1	1.19	1.38	1.60	1.81	2.02	2.24	2.44	2.68	2.97	3.19	3.46	3.77	4.15	4.41	4.88
4	.843	1	1.17	1.35	1.52	1.71	1.89	2.06	2.26	2.50	2.70	2.92	3.18	3.50	3.72	4.12
6	.723	.856	1	1.16	1.30	1.46	1.62	1.77	1.94	2.14	2.31	2.50	2.73	3.00	3.19	3.53
8	.626	.743	.866	1	1.13	1.27	1.41	1.53	1.68	1.86	2.00	2.17	2.36	2.60	2.76	3.06
10	.554	.657	.766	.885	1	1.12	1.24	1.35	1.48	1.64	1.77	1.92	2.09	2.30	2.45	2.70
12	.493	.586	.683	.788	.890	1	1.11	1.21	1.32	1.46	1.58	1.71	1.86	2.05	2.18	2.41
14	.446	.528	.616	.711	.804	.902	1	1.09	1.19	1.32	1.42	1.54	1.68	1.85	1.97	2.18
16	.409	.485	.567	.654	.740	.829	.919	1	1.10	1.21	1.31	1.42	1.55	1.70	1.81	2.00
18	.374	.443	.517	.596	.674	.756	.838	.912	1	1.11	1.19	1.29	1.41	1.55	1.65	1.82
20	.337	.400	.466	.538	.608	.683	.756	.824	.904	1	1.08	1.17	1.27	1.40	1.49	1.65
22	.313	.371	.434	.500	.565	.634	.703	.764	.839	.929	1	1.08	1.18	1.30	1.38	1.53
24	.289	.343	.400	.461	.521	.585	.649	.706	.774	.856	.924	1	1.09	1.20	1.28	1.41
26	.265	.314	.366	.423	.478	.536	.594	.647	.710	.786	.846	.916	1	1.10	1.17	1.29
28	.241	.286	.333	.385	.434	.488	.540	.588	.646	.714	.770	.834	.910	1	1.06	1.17
[a] 30	.227	.269	.314	.362	.409	.459	.508	.554	.606	.672	.724	.784	.855	.940	1	1.11
32	.205	.243	.284	.327	.370	.415	.460	.500	.549	.608	.654	.709	.774	.850	.905	1

[a] Green.

TABLE 24.—*Reduction factors for tamarack.*

[Compression parallel to grain—maximum crushing strength.

TO— Moisture per cent.	FROM— Moisture per cent.															
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.[a]	32.
2	1	1.09	1.21	1.35	1.53	1.74	2.00	2.27	2.50	2.72	2.90	3.07	3.20	3.30	3.40	3.51
4	.914	1	1.11	1.24	1.40	1.59	1.83	2.07	2.29	2.49	2.66	2.80	2.93	3.02	3.11	3.21
6	.826	.904	1	1.12	1.27	1.44	1.65	1.88	2.07	2.25	2.40	2.54	2.65	2.73	2.82	2.90
8	.739	.809	.894	1	1.13	1.29	1.48	1.68	1.85	2.01	2.15	2.27	2.37	2.44	2.52	2.60
10	.652	.714	.789	.882	1	1.14	1.30	1.48	1.63	1.78	1.89	2.00	2.09	2.15	2.22	2.29
12	.574	.628	.694	.776	.880	1	1.15	1.30	1.44	1.56	1.67	1.76	1.84	1.89	1.95	2.02
14	.500	.547	.606	.677	.768	.872	1	1.14	1.25	1.36	1.45	1.54	1.60	1.65	1.70	1.76
16	.441	.482	.533	.596	.676	.768	.881	1	1.10	1.20	1.28	1.35	1.41	1.45	1.50	1.55
18	.399	.437	.483	.540	.612	.696	.798	.906	1	1.09	1.16	1.23	1.28	1.32	1.36	1.40
20	.368	.402	.444	.497	.564	.640	.734	.833	.920	1	1.07	1.13	1.18	1.21	1.25	1.29
22	.344	.376	.417	.466	.528	.600	.688	.781	.862	.937	1	1.06	1.10	1.14	1.17	1.21
24	.326	.356	.394	.441	.500	.568	.651	.739	.816	.887	.946	1	1.04	1.08	1.11	1.15
26	.312	.341	.378	.422	.479	.544	.624	.708	.781	.850	.906	.958	1	1.03	1.06	1.10
28	.303	.331	.366	.410	.464	.528	.606	.688	.758	.825	.880	.929	.971	1	1.03	1.06
[a] 30	.294	.321	.355	.397	.451	.512	.587	.666	.735	.800	.853	.901	.941	.970	1	1.03
32	.285	.311	.344	.385	.437	.496	.569	.646	.712	.774	.826	.874	.912	.939	.969	1

[a] Green.